CELSS

Report of the First Planning Workshop for CELSS Flight Experimentation

Workshop for CELSS
Flight Experimentation
Ames Research Center,
Moffett Field, California
March 1987

NASA

National Aeronautics
and Space Administration
1988

Report of the First Planning Workshop for CELSS Flight Experimentation

John W. Tremor
TGS Technology, Inc.
Moffett Field, California

Robert D. MacElroy
NASA Ames Research Center
Moffett Field, California

TABLE OF CONTENTS

INTRODUCTION

The First Planning Workshop for CELSS Flight Experimentation was convened at Ames Research Center on March 23 and 24, 1987. Its aim was to establish a base upon which a CELSS Flight Experiment Program will be developed during the next several months. The charge given to the First Workshop participants was 1) to identify science requirements for CELSS flight experiments, and 2) to evaluate potential near-term CELSS flight experiment opportunities.

The meeting opened with a presentation by R.D. MacElroy of Ames of a brief overview of the CELSS program and a description of the rationales for CELSS flight experiments. In summary, the purpose of the CELSS program is to develop the scientific and technological base required for the construction and use of a bioregenerative life support system (BLSS) to support crews in extraterrestrial environments. A BLSS utilizes energy to grow photosynthetic organisms whose growth involves absorbtion of the crew's waste carbon dioxide, recycled water and mineral elements and the concommitant production of food, oxygen, and transpired water. A complete BLSS is capable of continuously recycling most life support materials through the use of waste-processing devices and of continuously regenerating consumed materials.

The potential uses of a BLSS include placement in a Growth Space Station on low Earth orbit (LEO), in a geosynchronous space station, on the surface of the Moon, in transit to Mars, and on the Martian surface. In each of these cases the gravitational and radiation environment is significantly different from that of Earth, where the plants and organisms useful in the BLSS evolved. It is therefore necessary to evaluate the response of higher plants and other organisms to be used in the BLSS, as well as some of the fluid handling machinery, to the space environment.

The gravity parameter is of greatest immediate significance to a space experimentation program. Space radiation, to some extent, can be simulated on the ground and, again to some extent, protected against in flight. Levels of gravity below unity can be achieved effectively only on flight missions. Knowledge of the behavior of systems in these microfields is essential for the design of a BLSS. The gravitational environment of the Space Station and possibly of a transit to Mars is in the microgravity range; lunar gravitational forces are about 1/6 g and Mars surface gravity about 38% of that of Earth.

In the case of Space Station, though it is relatively close to the Earth, costs of resupplying life support materials, including the logistics of resupply, have not been evaluated. It is therefore possible, particularly as the efficiency of a BLSS increases, that bioregeneration will supplement the more traditional life support systems. Transit to Mars may require, for reasons of human health, the imposition of artificial gravity on all or parts of the spacecraft. However, such a decision will not be made for some time. The usefulness of a BLSS, and its efficiency compared to other methods of life support, during a Mars transit has not been fully evaluated. However, the duration of the trip, and the potential need for psychological support of the crew through the supply of fresh food, increases the likelihood that a BLSS will be selected as part of the life support system.

Although both Lunar and Martian surface gravities are a substantial fraction of Earth's, it is essential to evaluate the behavior of crucial components of bioregenerative systems in equivalent gravitational environments. Long-term Lunar bases, and ultimately Martian bases, will be constructed with a BLSS as a critical part of the enabling technology. The only mechanism potentially available to achieve such tests before landing on these planetary surfaces will be centrifuges (or, ambitiously, tethered rotating systems) in a microgravity environment. It is expected that test centrifuges will be available on the Space Station and that tests of plant responses can be done in that environment.

MacElroy then outlined the first charge of the Workshop: the identification of science requirements for CELSS flight experiments. The conclusion of this introduction was that it is necessary to identify 1) the information that is required, 2) the experiments that will produce the information, 3) the environments that are required to conduct the experiments, and 4) the characteristics of the analyses to be performed, or the equipment required to do the experiments. The relationships among the information required, the experiments required to obtain the information, the experiment environmental conditions, and the analyses to be performed are illustrated in Figure 1.

MacElroy stated that the approach to CELSS Flight Experimentation will be to first establish a baseline and to determine whether potentially useful BLSS organisms and equipment behave the same or differently in the space environment compared to their behavior on Earth. To identify the space environment as the cause of anomalous behavior, it is essential to conduct biological experiments in environments that are predictable in their effects and as stress-free as possible in terms of promoting maximum productivity. If specimens behave differently, the second-level activity will be to identify countermeasures that will alter specimen behavior to enable them to fulfill their functions within the BLSS.

Thus, until a baseline is identified, it is not possible to determine the kinds of information that will be required to formulate corrective actions or counter-measures. Information gathered by flight experiment activities in the NASA Space Biology program will be very important in understanding biological responses to the space environment. The intent of the Space Biology program is to study basic mechanisms which govern plant responses to the space environment. It is anticipated that the goals of this program will increasingly coincide with those of the CELSS program once the baseline data for the practical uses of plants in space has been determined.

However, MacElroy emphasized that the principal goal of this First Workshop would be to focus specifically on the design for CELSS flight experiments involving higher plants. A secondary goal would be consider options for near-term flight opportunities as appropriate to achieve the goals of experimentation. As plant experiment proposals and mission assignments mature, other issues of significance to the CELSS flight program, such as bioreactors for the growth of algae and bacteria, and waste-processing and fluid-handling issues, would be addressed at subsequent Workshops.
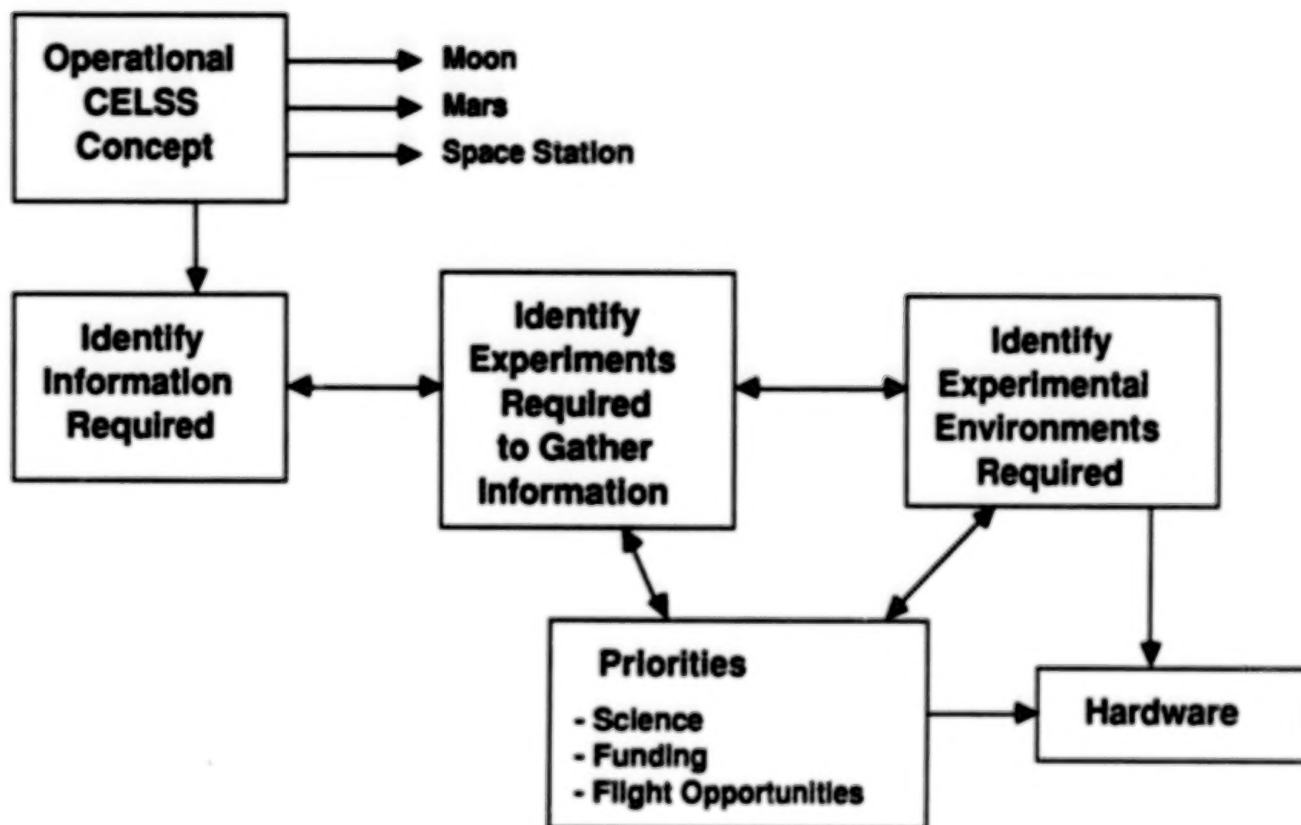
Figure 1.- Development of CELSS flight experiments science requirements.

PRESENTATIONS

Kenneth Souza, chief of the Life Science Project Office at Ames next related the project approach to "Flight Experiment Development." His presentation opened with a description of the structure of the project office and of the current flight mission involvements. The talk then covered the procedures for experiment and payload selection and implementation. Standard procedure is initiated by a proposal solicitation, usually an 'announcement of opportunity' letter, followed by submission and review of proposals by the American Institute of Biological Sciences (AIBS). The panel then recommends funding for proposals to the appropriate headquarters personnel. Field centers next perform a definition and feasibility evaluation of the proposals selected. Payload selection involves further payload definition, including requirements for resources and interfaces and costing and feasibility evaluation. After final selection the payload implementation process (which involves construction, testing, and installation on the appropriate carrier) occurs. Souza's talk concluded with a description of the kinds of life sciences experimental hardware under development and other hardware under consideration for Space Station flight. Souza's presentation lent perspective to the process of bringing experiments from concept to flight.

William Knott, manager of the Life Science Support Facility at Kennedy Space Center, gave the next presentation, entitled "Flight Experiment Launch Environment." He explained the sequence of steps involved in experiment processing: operations, logistics, and the support provided by launch center personnel. The various organizations involved with the launch of Shuttle payloads and their functions were described. Laboratory support is provided by the Biomedical Office, engineering support, and operations and checkout facilities are used in the final prelaunch phase. Among the issues discussed was the handling of specimens during the prelaunch phases; especially of interest were the time constraints imposed by launch protocols and the effect they have on organisms prior to launch.

"Flight Effects on Plants" was the subject covered by John Tremor of Santa Clara University. Summarized in Addendum 1, the responses to the flight environment of a number of plant species over a variety of flight and growth conditions were briefly presented as considerations in the design of future experiments. Summaries of results from experiments conducted on both weightlessness and radiation effects were presented. The result of this synopsis was to point out what we do know from previous flight experimentation, but equally importantly to outline what we don't know. This led to discussion about flight effects (vibration and acceleration), what kind of supporting studies and controls are necessary, and what types of species specific accomodations may be required to conduct desired experiments.

The "Elements of Flight Program Planning" and their relative importance and chronology in experiment development were next set forth by Lynn Griffiths of NASA Headquarters, Life Sciences Program. Difficulties in relating science and technology requirements as drivers of CELSS development to flight experiment opportunities and the ultimate uses of CELSS were made clear. The development schedule of 5 to 10 years was discussed. The Pre-Phase A is the initial feasibility evaluation; Phase A consists of refining concepts, costs, and schedules; evaluating options and technical

elements; and initiating technology development. Phase B refines science justifications and requirements and yields a detailed option definition, including technology, costs, and schedules. The Phase C/D sequences are the actual building, deployment, and operation of the experimental device. Reconciliation of science priorities with flight opportunities, budget cycles, equipment readiness, technology barriers, etc., leads to the determination of priorities and the actual costs and timetables required to complete the science objectives.

With the above as introduction and perspective, the participants were better prepared to discuss science requirements and possibilities for flight experimentation. These discussions were led, for the most part, by Frank Salisbury of Utah State University.

DISCUSSIONS

Salisbury initiated open discourse by presenting a prepared outline of CELSS problems and productivity considerations arising out of them (Addendum 2). A key point made by Salisbury in these opening observations was carried as an underlying theme through the remainder of the meeting. This theme pertains to the challenge presented by growing plants in a stress-free environment, with the genetic makeup of the plant as the primary limiting factor, and yield and productivity as the primary goal. His ground-based research with wheat is directed toward that goal, as is the work of other CELSS investigators. He made the further point that "so far, plants have never been grown in space in a relatively stress-free environment!" The validity of this observation stresses the importance of devising requirements for flight hardware and subsequently conducting a series of productivity-related experiments.

Salisbury spent some time describing his experiences in improving the productivity of wheat by manipulating environmental parameters and selecting cultivars. Lessons learned from this, and other ground-based work are applicable to the development of flight experiments and the selection of CELSS plant candidates. These issues are regarded critically in the determination of the science requirements and experimentation priorities set forth below. (Refer to Addendum 2 for details.)

A round table discussion of issues pertinent to determining science requirements for productivity experimentation in flight ensued. Joe Gale (NRC, NASA Ames) noted that radiation exposure over long durations will certainly be a factor of concern. He argued that properly shielded controls should be implemented in studying this effect. Complications of adequate dosimetry, methodology, and secondary radiation from high-Z particles were pointed out although it was agreed that radiation must be somehow taken into account, especially in regard to genetic and generational effects. It was noted that a great deal of the high-energy-particle-effect work can be better performed and controlled on the ground. An additional point was that the radiation dose limits for the crew will be quite low and that plants have a higher radiation tolerance.

Gale also called attention to the better relative efficiencies realized by smaller plants, e.g., algae and duckweed. We were reminded that although these smaller species were not by any means being ignored by the program (a number of investigators are being so supported), the goals of this first meeting were involved with higher plant applications.

The subject of a partial CELSS and its uses, primarily on a growth Space Station, was raised. Phillip Johnson of JSC stated that this should be strongly considered by a flight program since, among other factors, it has considerable support within the crew systems group as a source of fresh produce, distinct from a major contribution to a life support system. Productivity per se for such an application would not be so critical. Johnson also asked the question: Why hydroponics? The consensus in answer was that solid substrates have not been ruled out *a priori* for root support although hydro- and aeroponics, under study now, offer certain advantages in water and nutrient reclamation and freedom from nutrient binding. Further, a solid substrate may present disposal and microbe contamination problems.

These discussions led to several propositions: 1) That perhaps flight-testing could help us answer questions not directly concerned with science; 2) that there were a number of problems– such as gas/liquid interface; 3) that a Detailed Test Objectives (DTO) program would be helpful (e.g., Brown's substrate moisture experiment); and 4) that convection vs. fan-driven air problems probably exist that can only be answered by flight-testing. (The comment was later made that propositions 2 and 4 require expert counsel.) These discussions prompted the agreed-with statement of Steven Schwartzkopf (U.C. Davis) that a flight program must consider two sets of questions: 1) Basic Science Issues and 2) Hardware Issues.

Satisfactory hardware support relates directly back to the concept expressed by Salisbury that, in order to maximize productivity, a stress-free environment must be provided. Therefore, constraining factors of flight must be overcome by hardware design and component flight-testing prior to conducting biological experimentation.

Defining the goal of experimentation to promote increased plant productivity, and in particular, to uncover the effects of flight conditions on productivity, led to a discussion centered around conditions which might affect experiment design and/or CELSS operation. Space radiation, both external (long-wave, ionizing) and internally provided (PAR), and microgravity (to 0.00001) were first considered; then other conditions of flight were regarded as influential, e.g., vibration and acceleration, fluid interfaces, and hardware requirements. The latter were considered in some detail during the second day.

With these considerations as background and the CELSS generic experiments as listed in the "Greenbook" (Addendum 3, not included in this Report) as constituting a kind of checklist, the group outlined a number of desirable end-points, the final product being an "ultimate experiment" unconstrained by limited flight opportunities and conditions of support. This list of CELSS flight experiments went through modifications influenced by subsequent discussion, expressed finally as a priority list of space experimentation important to the design of a CELSS operating with optimal productivity (Table 1).

The following list describes the highest-priority experiments in greater detail.

1. The measurement of possible micro-gravity-induced ethylene production as an indication of plant stress was considered to be important, perhaps vital, in interpreting response to the flight environment.

2. Photosynthesis and respiration studies are critical. They are primary measures of productivity and of gaseous interchange, two major categories of a BLSS (in addition to waste management).

3. Orientation response of stem and root under microgravity conditions is important, especially to hardware configuration and possible countermeasure design.

4. "Seed-to-seed" experiments with crop plants are necessary, especially where the edible product is a flowering vegetable. Production of nonflowering veg-

TABLE 1: CELSS FLIGHT EXPERIMENTS

BIOENGINEERING

I. Develop a system able to monitor and control the plant environment

    A. Nutrient delivery

        1. Evaluate aeroponics, hydroponics, and matrix systems

    B. Shoot environment

        1. CO_2 monitoring and control

        2. Lighting systems (power and heat-removal requirements)

        3. Environmental control (temperature, humidity, atmosphere compostion)

II. Fluid interfaces (verify technology readiness)

PLANT PHYSIOLOGY

I. Productivity

    A. Photosynthesis/respiration (gas exchange)

    B. Orientation (roots and shoots)

        1. Light, electricity, magnetism and centrifuge

    C. Vegetative morphology

        1. Throughout complete life cycle (e.g., stem, root, leaf weight, and leaf area)

        2. Stomate formation/transpiration

        3. Internode elongation

        4. Release of apical dominance

        5. Tuber and root formation and development

        6. Tillering in cereal plants

    D. Ethylene (organic volatiles) and effects of microgravity on the above processes and responses

II. Reproductive development

III. Seed to seed

    A. Use various crop species

    B. Refine protocol after analysis of issues raised by previous experiments

IV. Other, more specialized experiments

    A. Interactions among organisms

        1. Allelochemical effects

        2. Multispecies interactions

        3. Plant/microbe interactions

etables (e.g., lettuce) falls ultimately into this category since seed must be formed to ensure succession, vegetative propagation and exotic technologies (e.g., tissue culture) aside.

5. Partitioning of assimilates is related to the above. It is important to determine the quality and quantity of the major dietary constituents as influenced by growth in flight.

6. Microbial growth must be described because it may affect productivity and constitute a possible pathogenic hazard.

7. The study of reproductive development is important as it relates to fruit development. Flower initiation, pollination, and seed formation may be affected by microgravity. It is important to consider photo and thermal periodicism requirements or the artificial triggering of reproductive development.

8. Morphological development at all stages should be defined, including node elongation, tillering (in cereal grains), release of apical dominance, and tuber and root enlargement.

9. Algae or *lemna* experimentation was proposed as informative of basic productivity, organelle changes, genetic variation, and multigenerations of vegetative growth over relatively short-term studies.

In support of such experimentation, it was again emphasized that engineering tests assume a high priority in assuring satisfactory support of experimental material and in the development of components. Gale noted that, to supplement the effort of formally named PIs, it would be most efficient to have a team of plant physiologists from a variety of backgrounds prepared to analyze plants upon their return in order to extract the greatest amount of information from each experiment. Further, the importance of research on a number of different species as flight candidates for the above studies was mentioned as was a due consideration for acceleration, vibration, and other controls for providing standards of interpretation. This is critical because many plants, for one reason or another, may simply not grow well under flight conditions. Hence, a fair number (e.g., 12-15 species) of successfully ground-tested (in closed systems) plants should be made available.

Pearl Cheng of the Ames Life Sciences Project Office then gave a presentation on the proposed LifeSat reusable satellite. General consensus was that the power limitations of the vehicle would prohibit extensive use by the CELSS flight program, but that simple experiments, perhaps using the plant growth unit (PGU), would be appropriate and would offer the first realistic opportunity to begin addressing CELSS flight issues.

The prioritization of experiments was made with several constraints in mind. Lynn Griffiths spoke of flight opportunities and discussed approaches to minimizing constraints arising from competition for resources and flight time. For Space Station, a well-defined experimental protocol, including mass, power, and volume requirements, and equipment specifications and crew time, is essential. Such a protocol should be

submitted within the next year in order to allow negotiation for flight time on the Space Station.

The importance of providing a centrifuge as a control was discussed. It was agreed earlier that CELSS has less need for a 1-g control than does the Space Biology program where explanations of fundamental mechanisms of gravity response are of overriding importance. However, an early determination of the effects of Lunar and Mars gravity levels on the BLSS design is of importance to the CELSS program despite confidence expressed in the literature that even the 0.16 g exerted by the moon is adequate to provide the desired orientation of stem and root and a "normal" physiological response. Only flights at zero gravity with an on-board centrifuge can give us this information or information about the minimal g levels required if zero gravity imparts difficult problems in plant productivity. It was agreed that this need is strong enough to buttress the present advocacy for a Space Station centrifuge that, with suitable biological preparations, could begin to answer these questions for CELSS.

For the Space Transportation System (STS), Shuttle mid-deck lockers were briefly considered, but the most appropriate option was decided to be the Spacelab. Dedicated life science missions and the International Microgravity Laboratory (IML) missions were discussed. Both require well-developed protocols, and no flights before 1992 can be expected. Free-flyers, such as EURECA, were also discussed, especially in the context of a comprehensive experiment. This type of carrier raised questions concerning the state of readiness for automation and robotics necessary to monitor and control the experiment properly. H. P. Klein of Santa Clara University advocated the development of an experiment set, prioritized independently of carrier opportunities, followed by selection based on a realistic appraisal of flight opportunities. Klein also mentioned the Industrial Space Facility plan to fly a free-flyer of prospectively high power capability and long duration, 2 to 3 years before Space Station IOC, and indicated that it was a valuable flight opportunity.

In order to achieve the experiments outlined, it was decided that three sets of hardware will be required. First would be a modified PGU for use in the near term, perhaps on LifeSat or Shuttle mid-deck. Next would be a small (two to three mid-deck lockers) Plant Growth Facility (PGF), useful for both bioengineering verification and plant physiology experiments. The final device would be an upgrade of the PGF to accomodate all the requirements to perform essential CELSS experiments. Thus, development of appropriate flight hardware was directed towards a capability of providing support for comprehensive experimentation, with modifications being made in favor of less complex hardware depending upon availability of resources and flight opportunities. Ron Mancini of the Ames Mechanical Systems and Control Branch led the group through a hardware development exercise which resulted in "Idealized Requirements for Flight Hardware Support and Monitoring" directed specifically towards the scenario of CELSS flight experiments as previously defined by the workshop participants. The results of this discussion are shown in Table 2.

I. Basic Hardware Subsystems

   A. Light System
      1. 0 to 400-2000 μmoles/m^2/sec $\pm$ 5%
      2. Controllable day/night cycle, set points
      3. Uniform illumination
      4. Wavelengths found in incandescent, fluorescent, and high-intensity discharge (HID) lamps
      5. "Lights on/off" indication (intensity monitor optional)

   B. Life Support System
      1. Atmosphere constituent control (leaf and stem area)
        a. Total pressure control (P $\pm$10%) (monitor within 1 mm Hg)
        b. Constituents (partial pressures??)

1) O_2	23.8% $\pm$5%
2) CO_2	0 to 5000 ppm, $\pm$0.2%
3) H_2O (humidity)	10-25 mm Hg $\pm$5% ideal, $\pm$10% acceptable Controlled humidity Day/night set points
4) Ethylene	<5 ppb (control and monitor)
5) N_2	Makeup to obtain "P" pressure

        c. Integral gas chromatograph
        d. Scrubbing system for CO
        e. Scrubbing system for volatile organics

f. Air flow	0.1 to 1 m/sec 100 to 400 vol/hr. Mixed air (no "dead" areas in chambers)
g. Air temperature	10 to 35 °C $\pm$5 °C Day/night set points 1 °C uniformity within chamber

      2. Food/Nutrient Delivery (root zone)

a. Liquid nutrient	Line-fed membrane/substrate Use premixed makeup solution Control pH (continuously) Monitor conductivity (continuously) Monitor and control specific elements in the nutrients (if possible/feasible) Monitor to trigger addition of pre-set amounts of nutrient
b. Nutrient temperature	10 to 35 °C $\pm\frac{1}{2}$ °C at setpoints
c. Pressure	Maintain slightly lower than growth pressure
d. Gases	O_2 – nutrient > 80% saturated O_2 (7-8 ppm) CO_2 – $\leq$ 1% atm. above solution N_2 – makeup to maintain pressure Ethylene – < 5 ppb H_2O – saturated

C. System Monitoring/Data Requirements (separate from control functions)
1. Temperature
a. Leaf
b. Air
c. Root
2. Light intensity
3. Pressure
4. Gases
5. Air flow
6. Nutrient parameters
7. Ionizing radiation
8. Vibration (acceleration)
9. Video
10. Plant sampling/harvest

D. Plant Chamber Requirements
1. Size
a. Four chambers minimum
b. $1 \text{ m}^2 \times 1\frac{1}{2}$ m high
c. Variable root zone capability
2. Barrier between lights and chamber
3. Barrier between roots and chamber atmosphere
4. Glove box/air lock for sampling/harvesting
5. Observation window
6. Chamber closed to cabin environment

E. Power

Constrained by Space Lab or other vehicle capabilities

II. Other Hardware Requirements

A. Shielding

B. Vibration (control, monitoring)

CONCLUSIONS

Certain summary conclusions can be drawn from the proceedings. There was general agreement that:

1. A CELSS Flight Experimentation Program is necessary based upon:

    a. the rationale of designing hardware functional in various space mission environments and ultimately in the microgravity and radiation environments of Lunar and Martian bases.

    b. the definition of science requirements arising from the need to optimize higher plant productivity in CELSS-supported missions.

2. The kind of information necessary for productivity assessment has been identified.

3. Generic experiments necessary to gather that information have been identified and prioritized.

4. General problems of hardware and equipment have been defined.

5. It is necessary for that hardware to provide a stress-free environment, not only to maximize productivity, but to also make more readily identifiable disturbing mission factors.

ADDENDUM 1

Flight Experiments Past – Plants

I Weightlessness Effects

    What we know or suspect
        Cells round, cellular inclusions disperse
        Stems and roots differ in length from controls
        Maybe some effect at subcellular level
        Root and shoot orientation according to species
        Lignin response
        Seed-to-seed growth with some response

    What we don't know
        Species-specific g-response (0.01 to 0.00001 g)
        Light-cueing thresholds
        Response to discrete micro-g levels (0.38 g, 0.16 g)
        Vibration/acceleration/radiation interactions
        Nutrient partitioning
        Different crop plant response through generations
        "Preadapted" species

II Radiation Effects

    What we know or suspect
        Damage does occur
        More sensitive in growing stages
        Seed storage may be a problem

    What we don't know
        Radiation/gravity synergism~antagonism
        Species/stage sensitivity
        Mutation rates
            plants
            microbiological associations
        Long-term exposure to high-Z particles

Specific considerations concerning interpretation and hardware

    Preflight studies/experiments required
    Controls necessary
        in-flight
        ground
        gravity alteration complications
    Vibration levels tolerated
    Species specific accomodations
        lighting
        support
        waste-management products
    System accomodations to micro-g environment

ADDENDUM 2

SCIENCE REQUIREMENTS

Facilitator: F. B. Salisbury
Utah State University

THE BASIC CELSS PROBLEMS:

1. PLANT PRODUCTION – this is the one that can use space experimentation.

   And that depends on where and how a CELSS is used: space station, long voyage, Lunar or Martian surface colony.

   But future development will determine how it might be used:

   > How big a problem is weightlessness?

   > How expensive and how reliable can we make a CELSS?

   An important problem of plant production is that of CLOSURE; can we grow highly productive plants in a completely closed system?

2. FOOD PREPARATION – most important study, but probably does not need weightlessness experimentation for a while: only after we know whether plant production can be efficient in weightlessness.

3. WASTE DISPOSAL or RECYCLING – in the same catagory as food preparation.

4. CONTROL SYSTEMS – likewise, but this also involves question of closure.

THE BASIC FOOD-PRODUCTION PROBLEM: How will weightlessness affect productivity? All other problems are secondary, including all basic problems of the mechanisms of plant growth.

If productivity is reduced (as seems quite possible, based on the few imperfect experiments that have been done), then we will ask why?

Basic research might well be required to solve such a problem.

But first we must see if there is a problem.

SO FAR, PLANTS HAVE NEVER BEEN GROWN IN SPACE IN A RELATIVELY STRESS-FREE ENVIRONMENT!

Actually, plants on Earth have never been grown in completely stress-free environment, although our plants come very close!

TAKE A QUICK LOOK AT OUR SET-UP:

We have three basic units: chambers (3), greenhouse, and photoperiod room.

Consider the CHAMBERS:

CO2 ENRICHMENT: we find 1000 μmol/mol to be best: very important.

TEMPERATURE: need a range for study, but it is very important.

RADIANT ENERGY (LIGHT): we get to sunlight at noon on a summer day (2000 μmol/m^2/s); mostly with high-pressure sodium lamps; this is critical; hope to increase soon.

A HYDROPONIC SYSTEM requires:

Good aeration, which we achieve with rapid circulation and cascading.

Proper mixture; will ours work in space as well?

Support system to allow high densities.

This has SPECIAL PROBLEMS for APPLICATION IN WEIGHTLESSNESS (maybe Tom Dreschel has solved it–but it is a cumbersome system).

Consider the IMPORTANCE OF CULTIVARS.

CONSIDER SOME OF OUR RESULTS (and note also Wisconsin and Purdue):

CULTIVARS: They make a HUGE (two- to three-fold) difference.

We recently found Veery 10 to yield about 30% better than Yecora Rojo, which we thought was so good that it couldn't be beat.

We have also done some BREEDING of our own: good success.

YIELD STUDIES: basis of g/m^2/d.

A high field yield	7.0 g/m^2/d	
The World Record field yield	14.0 g/m^2/d	
Utah CELSS project (early 1986)	24.0 g/m^2/d	Harvest Index: 25%
Abstract from soviets	76.9 g/m^2/d	(4000–6000 mmol/m^2/s, 4000 plants/m^2)
Utah, Dec. 2, 1986	60.3 g/m^2/d	Harvest Index: 43.9%
Area Calculation	12 to 30 m^2/person	

WHY DID WE FINALLY ACHIEVE SUCH HIGH YIELDS?

High CO2: 1200 μmol/mol. But this is "as usual."

Lower temperature than before (means longer life cycle): 20/15 °C.

A range of light levels: 400 to 2000 μmol/m²/s.

Shorter photoperiod than before (also longer life cycle): 20 h.

Higher density than before: 2000 plants/m².

Rock wool, 5 to 10x field.

A bit higher phosphorus than before.

SOME MOST IMPORTANT CONCLUSIONS:

1. Yield is a straight-line function of irradiance! (NO SATURATION!)

2. Efficiency drops with increasing light.

3. At low light levels, efficiency is close to theoretical values.

4. The last tillers to form are not efficient (need uniculm).

SO WHAT ARE THE SCIENCE REQUIREMENTS FOR A GOOD CELSS EXPERIMENT IN SPACE?

1. Control of CO_2. (Too high quickly becomes toxic to plants.)

2. Control of temperature; should also cycle.

3. HIGH LIGHT LEVELS!!! (This is absolutely essential for CELSS test.)

4. Control of photoperiod. (Temperature might be more important.)

5. Control of humidity. (Not discussed much, but also important.)

6. A good support system that allows HIGH DENSITIES:
A CANOPY OF PLANTS!

7. TIME to complete a life cycle – or some significant portion of it.

8. Sufficient VOLUME for a mature crop.

WITH THAT AS A STARTER, LET THE COLLECTIVE MIND DETAIL FUTHER REQUIREMENTS.

ACTUALLY THERE ARE SEVERAL PROBLEMS WITH WHEAT THAT CAN BE
STUDIED (the ones marked with * may well be influenced by microgravity and would
surely influence yield):

VEGETATIVE GROWTH:

Germination of seeds.

Shoot morphogenesis (in tissue culture, maybe).

Orientation of shoots and roots.* (Clinostat evidence says light will
orient; studies could be done with seedlings.)

Elongation of mature nodes.* (Occur on a clinostat; effect on yield?)

Tillering.* (Don't know what to expect; strongly influences yield.)

Partitioning of assilimates to leaves, roots, stems (architecture).*

REPRODUCTIVE GROWTH:

Floral initiation.* (Clinostatt evidence says it is influenced in other
species; careful studies not yet done with wheat.)

Pollen development, embryosac formation (don't know what to expect).

Pollination* and fertilization. (Pollination might be influenced; don't
know what to think about fertilization.)

Embryo and seed development (filling and maturation; don't know what
to expect).

Somatic embryoid formation (studied in tissue culture).

Viability of resulting seeds.* (Soviet work suggests an effect.)

Attendees to the
First Planning Workshop
for
CELSS Flight Experimentation

Dr. Rod Ballard
NASA Ames Research Center
Mail Stop 240A-3
Moffett Field, CA 94035
415 694 6748

Dr. Sherwood Chang
NASA Ames Research Center
Mail Stop 239-10
Moffett Field, CA 94035
415 694 5733

Ms. Pearl L. Cheng
NASA Ames Research Center
Mail Stop 240A-3
Moffett Field, CA 94035
415 694 6918

Dr. James P. Connolly
NASA Ames Research Center
Mail Stop 213-2
Moffett Field, CA 94035
415 694 6483

Dr. Joe Cowles
Department of Biology
University of Houston
Houston, TX 77004
713 749 3135

Dr. Donald DeVincenzi
Deputy Chief, Life Science Division
NASA Ames Research Center
Mail Stop 239-17
Moffett Field, CA 94035
415 694 5760

Dr. Joseph Gale
Department of Botany
Institute of Life Sciences
Hebrew University of Jerusalem
Jerusalem, 91904 ISRAEL
[01 972] (0)2 585-201

Dr. John J. Givens
NASA Ames Research Center
Mail Stop 244-14
Moffett Field, CA 94035
415 694 5696

Dr. Lynn Griffiths
NASA Headquarters
Code EBX
Washington, D.C. 20546
FTS 453 1525

Mrs. Caye Johnson
NASA Ames Research Center
Mail Stop 240-9
Moffett Field, CA 94035
415 694 5768

Dr. Philip Johnson,Jr.
NASA Johnson Space Center
Code SD3
Houston, TX 77058
FTS 525 7111
713 483 7111

Dr. Harold P. Klein
Department of Biology
The University of Santa Clara
Santa Clara, CA 95053
415 856 7656

Dr. Morris Klein
Department of Botany
Ohio State University
1735 Neil Avenue
Columbus, OH 43210
614 292 5213

Dr. William Knott
Biomedical Office
Code MD-ENV
Kennedy Spacecraft Center, FL 32899
FTS 253 5142
305 853 5142

Dr. Robert D. MacElroy
NASA Ames Research Center
MS 239-4
Moffett Field, CA 94035
415 694 5573

Dr. Bruce Macler
NASA Ames Research Center
Mail Stop 239-4
Moffett Field, CA 94035
415 694 5201

Dr. Ronald E. Mancini
NASA Ames Research Center
Mail stop 239-7
Moffett Field, CA 94035
415 694 6319

Dr. Salvador A. Rositano
NASA Ames Research Center
Mail Stop 213-2
Moffett Field, CA 94035
415 694 5480

Dr. Frank B. Salisbury
Plant Science Department
Utah State University
Logan, UT 84322-4820
FTS 586 2237
801 750 2237

Dr. H. W. Scheld
PhytoResource Research Inc.
707 Texas Avenue, Suite 202D
College Station, TX 77840
409 693 8606

Dr. Steven H. Schwartzkopf
NASA Ames Research Center
Mail Stop 239-10
Moffett Field, CA 94035
415 694 6055

Dr. Elliot Shubert
Department of Biology
Box 8238
U. North Dakota
Grand Forks, ND 58202
FTS 8 783 5771
701 777 4666

Dr. Kenneth Souza
NASA Ames Research Center
Mail Stop 240A-3
Moffett Field, CA 94035
415 694 5736

Dr. John Tremor
NASA Ames Research Center
Mail Stop 239-4
Moffett Field, CA 94035
415 694 5542

Dr. Theodore Wydeven,Jr.
NASA Ames Research Center
Mail Stop 239-4
Moffett Field, CA 94035
415 694 5738

Dr. Richard S. Young
RCA Government Services
476 Highway A1A, Suite 2
Satellite Beach, FL 32937
305 853 3404

Controlled Ecological Life Support Systems (CELSS)
A Bibliography of CELSS Documents Published as NASA Reports

1. Johnson, Emmett J.: Genetic Engineering Possibilities for CELSS: A Bibliography and Summary of Techniques. NASA CR-166306, March 1982.

2. Hornberger, G.M. and Rastetter, E.B.: Sensitivity Analysis as an Aid in Modelling and Control of (Poorly-Defined) Ecological Systems. NASA CR-166308, March 1982.

3. Tibbitts, T.W. and Alford, D.K.: Controlled Ecological life Support System: Use of Higher Plants. NASA CP-2231, May 1982.

4. Mason, R.M. and Carden, J.L.: Controlled Ecological Life Support System: Research and Development Guidelines. NASA CP-2232, May 1982.

5. Moore, B. and MacElroy, R.D.: Controlled Ecological Life Support System: Biological Problems. NASA CP-2233, May 1982.

6. Aroesta, H.: Application of Guided Inquiry System Technique (GIST) to Controlled Ecological Life Support Systems (CELSS). NASA CR-166312, January 1982.

7. Mason, R.M.: CELSS Scenario Analysis: Breakeven Calculation. NASA CR-166319, April 1980.

8. Hoff, J.E., Howe, J.M. and Mitchell, C.A.: Nutritional and Cultural Aspects of Plant Species Selection for a Controlled Ecological Life Support System. NASA CR-166324, March 1982.

9. Averner, M.: An Approach to the Mathematical Modelling of a Controlled Ecological Life Support System. NASA CR-166331, August 1981.

10. Maguire, B.: Literature Review of Human Carried Microbes' Interaction with Plants. NASA CR-166330, August 1980.

11. Howe, J.M. and Hoff, J.E.: Plant Diversity to Support Humans in a CELSS Ground-Based Demonstrator. NASA CR-166357, June 1982.

12. Young, G.: A Design Methodology for Nonlinear Systems Containing Parameter Uncertainty: Application to Nonlinear Controller Design. NASA CR-166358, May 1982.

13. Karel, M.: Evaluation of Engineering Foods for Controlled Ecological Life Support Systems (CELSS). NASA CR-166359, June 1982.

14. Stahr, J.D., Auslander, D.M., Spear, R.C. and Young, G.E.: An Approach to the Preliminary Evaluation of Closed-Ecological Life Support System (CELSS) Scenarios and Control Strategies. NASA CR-166368, July 1982.

15. Radmer, R., Ollinger, O., Venables, A. and Fernandez, E.: Algal Culture Studies Related to a Closed Ecological Life Support System (CELSS). NASA CR-166375, July 1982.

16. Auslander, D.M., Spear, R.C. and Young, G.E.: Application of Control Theory to Dynamic Systems Simulation. NASA CR-166383, August 1982.

17. Fong, F. and Funkhouser, E.A.: Air Pollutant Production by Algal Cell Cultures. NASA CR-166384, August 1982.

18. Ballou, E. V.: Mineral Separation and Recycle in a Controlled Ecological Life Support System (CELSS). NASA CR-166388, March 1982.

19. Moore, B., III, Wharton, R. A., Jr., and MacElroy, R.D.: Controlled Ecological Life Support System: First Principal Investigators Meeting. NASA CP-2247, December 1982.

20. Carden, J. L. and Browner, R.: Preparation and Analysis of Standardized Waste Samples for Controlled Ecological Life Support Systems (CELSS). NASA CR-166392, August 1982.

21. Huffaker, R. C., Rains, D. W. and Qualset, C. O.: Utilization of Urea, Ammonia, Nitrite, and Nitrate by Crop Plants in a Controlled Ecological Life Support System (CELSS). NASA-CR 166417, October 1982.

22. Gustan, E. and Vinopal, T.: Controlled Ecological Life Support System: Transportation Analysis. NASA CR-166420, November 1982.

23. Raper, C. David, Jr.: Plant Growth in Controlled Environments in Response to Characteristics of Nutrient Solutions. NASA CR-166431, November 1982.

24. Wydeven, T.: Composition and Analysis of a Model Waste for a CELSS. NASA Technical Memorandum 84368, September 1983.

25. Averner, M., Karel, M., and Radmer, R.: Problems Associated with the use of Algae in Bioregenerative Life Support Systems. NASA CR-166615, November 1984.

26. Radmer, R., Behrens, P., Fernandez, E., Ollinger, O., Howell, C., Venables, A., Huggins, D. and Gladue, R.: Algal Culture Studies Related to a Closed Ecological Life Support System (CELSS). NASA CR-177322, October 1984.

27. Wheeler, R. and Tibbitts, T.: Controlled Ecological Life Support System: Higher Plant Flight Experiments. NASA CR-177323, November 1984.

28. Auslander, D., Spear, R., Babcock, P. and Nadel, M.: Control and Modeling of a CELSS (Controlled Ecological Life Support System). NASA CR-177324, November 1984.

29. Karel, M. and Kamarei, A.R.: Feasibility of Producing a Range of Food Products from a Limited Range of Undifferentiated Major Food Components. NASA CR-177329, April 1984.

30. MacElroy, R.D., Smernoff, D.T., and Klein, H.: Life Support Systems in Space Travel. (Topical Session of XXVth COSPAR meeting, Graz, Austria) NASA CP-2378, May 1985.

31. MacElroy, R.D., Martello, N.V., Smernoff, D.T.: Controlled Ecological Life Support Systems: CELSS '85 Workshop, NASA TM-88215, January 1986.

32. Tibbitts, T.W.:Controlled Environment Life Support System: Calcium-Related Leaf Injuries on Plants. NASA CR-177399, March 1986.

33. Tibbitts, T.W., Wheeler, R.M.: Controlled Environment Life Support System: Growth Studies with Potatoes, NASA CR-177400, March 1986.

34. Babcock, P.S.: Nonlinear System Controller Design Based on Domain of Attraction: An Application to CELSS Analysis and Control, NASA CR-177401, March 1986.

35. Smernoff, D.T.: Atmosphere Stabilization and Element Recycle in an Experimental Mouse-Algal System, NASA CR-177402, March 1986.

36. Oleson, M., Olson, R.L.: Controlled Ecological Life Support Systems (CELSS): Conceptual Design Option Study, NASA CR-177421, August 1986.

37. Oleson, M., Slavin, F., Liening, R., Olson, R.: Controlled Ecological Life Support Systems (CELSS): Physiochemical Waste Management Systems Evaluation, NASA CR-177422, August 1986.

38. Knox, J.: A Method of Variable Spacing for Controlled Plant Growth Systems in Spaceflight and Terrestrial Agriculture Applications, NASA CR-177447, February 1987.

39. Radmer, P., Arnett, K., Gladue, R., Cox, J., Lieberman, D.: Algal Culture Studies for CELSS, NASA CR-177448, February 1987.

40. Karel, M., Nakhost, Z.: Utilization of Non-Conventional Systems for Conversion of Biomass to Food Components, NASA CR-177449, February 1987.

41. MacElroy, R.D., Smernoff, D.T., Rummel, J.: Controlled Ecological Life Support Systems: Design, Development and Use of a Ground-Based Plant Growth Module, NASA CP-2479, June 1987.

42. MacElroy, R.D., Smernoff, D.T.: Regenerative Life Support Systems in Space, (Topical Session of XXVIth COSPAR meeting, Toulouse, France), NASA CP-2480, June 1987.

NASA — Report Documentation Page

National Aeronautics and
Space Administration

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CP 10020		

4. Title and Subtitle	5. Report Date
Report of the First Planning Workshop for CELSS Flight Experimentation	November 1988
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
John W. Tremor (TGS Technology, Inc., Moffett Field, CA) and Robert D. MacElroy	A 88265
	10. Work Unit No.
	199-61-32-01

9. Performing Organization Name and Address	11. Contract or Grant No.
Ames Research Center Moffett Field, CA 94035	
	13. Type of Report and Period Covered

12. Sponsoring Agency Name and Address	Conference Publication
National Aeronautics and Space Administration Washington, DC 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

Point of Contact: Robert D. MacElroy, Ames Research Center, M/S 239-4
Moffett Field, CA 94035 (415) 69:-5573 or FTS 464-5573

16. Abstract

This report summarizes a workshop held March 23 and 24, 1987 to establish a base upon which a CELSS flight experiment program will be developed. The kind of information necessary for productivity assessment was determined. In addition, generic experiments necessary to gather that information have been identified and prioritized. General problems of hardware and equipment have been defined. The need for the hardware to provide a stress-free environment, not only for productivity, but also to make more readily identifiable disturbing mission factors, was recognized.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
CELSS Flight experiments Life support	Unclassified-Unlimited Subject Category-54

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	27	A02

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, Virginia 22161

END

DATE

FILMED

MAR 2   1989